

# APPLICATION OF HARLIE MEASUREMENTS IN MESOSCALE STUDIES: MEASUREMENTS OF AEROSOL BACKSCATTER AND WINDS DURING A GUST FRONT.

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## 1. INTRODUCTION

Lidar atmospheric systems have required large telescope for receiving atmospheric backscatter signals. Thus, the relative complexity in size and ease of operation has limited their wider use in the atmospheric science and meteorology community. The Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE) uses a scanning holographic receiver and demonstrates that these issues can be overcome.

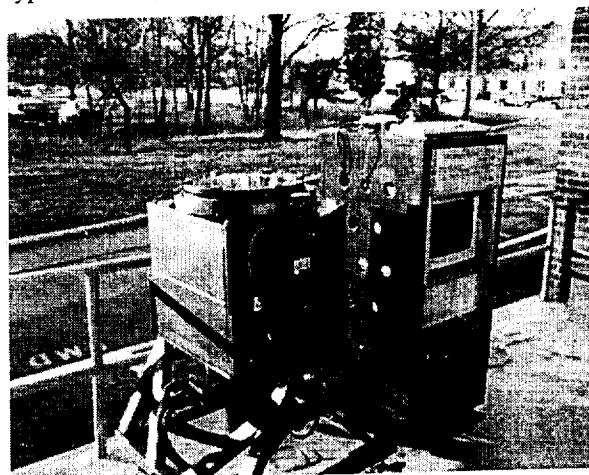
HARLIE participated at the DOE-ARM Southern Great Plains site (CART) during the Water Vapor Intensive Operation Period (WVIOP2000) held September-October 2000. It provided exceptional high temporal and spatial resolution measurements of aerosol and cloud backscatter in three dimensions. HARLIE recorded over 110 hours of data were recorded on 16 days between 17 September and 6 October 2000. Placed in a ground-based trailer for upward looking scanning measurements of clouds and aerosols, HARLIE provided a unique record of time-resolved atmospheric backscatter at 1-micron wavelength. The conical scanning lidar measures atmospheric backscatter on the surface of an inverted 90 degree (full angle) cone up to an altitude of 20 km. 360-degree scans having spatial resolutions of 20 meters in the vertical and 1 degree in azimuth were obtained every 36 seconds during the daily operating period.

In this study we present highlights of HARLIE-based measurements of the boundary layer and cloud parameters as well as atmospheric wind vectors where there is sufficiently resolved structure in the backscatter. In particular we present data and discussions from a bore-front case observed on 23 September 2000.

Several lidar, radar and conventional instruments operated during the WVIOP2000 at CART. But, first a brief description of HARLIE instrument is given below.

## 2. HARLIE: INSTRUMENT DESIGN

Scanning holographic lidar receivers (Schwemmer, 1993) are based on volume phase holograms made in dichromated gelatin (DCG) sandwiched between 2 layers of high quality float glass. The use of this innovation in HARLIE allows for several advantages: a compact design of scanning lidar systems at 532 and 1064 nm wavelengths, the ability to withstand moderately high laser power and energy loading, sufficient optical quality for most direct detection systems, overall efficiencies rivaling conventional receivers, and the stability to last several years under typical lidar system environments.



**Figure 4** photograph of the HARLIE transceiver assembly and electronics rack.

HARLIE is an experimental technology demonstration that uses a holographic scanning telescope and operates at the 1064 nm wavelength of a Nd:YAG laser (Fig. 1). It scans in a 45-degree (half angle) cone, usually with the scan axis vertical so that the elevation angle is a constant 45 degrees. It rotates continuously in azimuth,

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at rates as high as 30 rpm. It can also be tipped at 45 degrees and kept pointed in a fixed direction so that conventional vertical pointing measurements can also be used. The scanning data provides a pseudo-3D visualization of aerosol backscatter, and principal data products include aerosol backscatter profiles, cloud bottom and top heights, boundary layer heights and entrainment zone thickness. In addition, coherent structures in the backscatter field can be tracked as they progress across the conical scan surface, resulting in an estimation of the wind speed.

**Table 1: Summary of HARLIE Specifications**

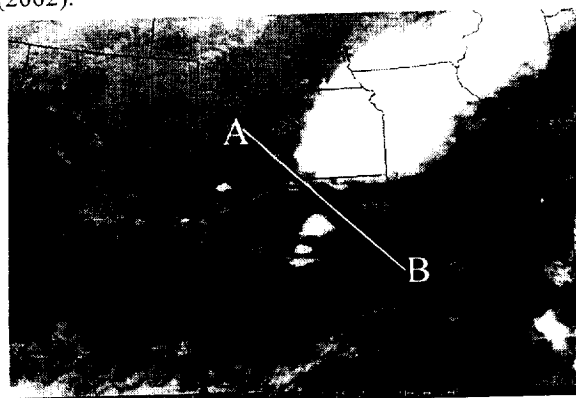
<b>Transceiver Assembly</b>
Weight: 118 kg.
Overall dimensions (in cm, minus mounting rails): 56 w x 69 l x 102 h
Transmitter: diode pumped Nd:YAG, 1064nm wavelength, 1 mJ, 40 nsec pulse length, 5 kHz rep-rate, 100 $\mu$ rad divergence
Receiver: 40 cm diameter, f/2.5 volume phase HOE, 45° diffraction angle, effective collection area 1064 cm <sup>2</sup> , 200 $\mu$ rad FOV, 0.5 nm bandpass
Detector: Geiger mode or analog Silicon APD
<b>Electronics Rack</b>
Weight: 125 kg
Overall dimensions (cm): 56 w x 64 l x 127 h
Power requirements: 1000 W max. @110 Vac., 19 amps peak (2.2 kVA peak)
<b>Scanners</b>
Scan Modes: Point and stare, 8 position step-stare, Continuous scan (30rpm)
Azimuth (scan) pointing resolution: 12.5 $\mu$ rad
<b>Data System</b>
Two ping-ponged 24 bit x 8192 bin scalars
Range resolution: 30 m
Integration time: 100 msec

### 3. HARLIE: MEASUREMENT EXAMPLES

#### 3.1 Aerosol Backscatter: 23 September 2000

An interesting case of a solitary wave, leading a cold frontal passage, was observed on 23 September 2000 over the CART site. This front, associated with a low pressure system moving southeast toward the northern Oklahoma border, was forecasted to pass at 0400 UTC. Analysis of the Raman lidar data showed that in fact the surface frontal passage was at 0930 UTC, and what passed at 0400 was a rope cloud associated with a pressure jump (undular bore) visible in the satellite images (Fig. 2). A discussion of the synoptic, upper air

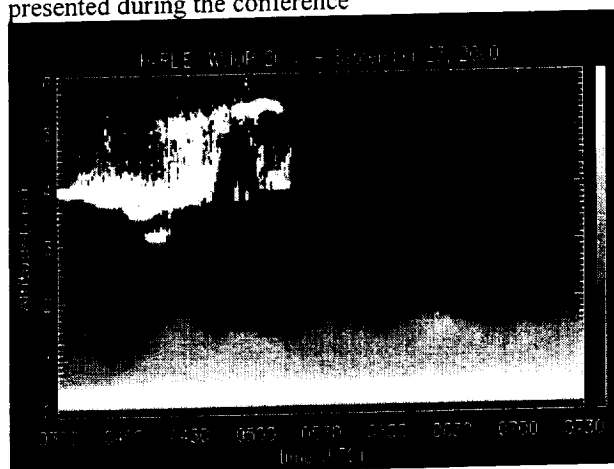
and surface measurements are presented in Demoz et al. (2002).



**Figure 2.** Satellite (enhanced) and surface observations at 0315 UTC, on 23 September 2000. The DOE ARM site is denoted by dot over northern OK.

We present a 1-minute average, time-height profile images of the aerosol backscatter measurements recorded using HARLIE in Fig. 3. The figure may be assumed to represent the vertical structure along the line AB shown in fig 2. It clearly reveals the characters of the bore undulations: a wavelength of 35minute, a damped oscillation, a cloud at the first peak – revealing enough mechanical lifting of air parcels beyond the lifting condensation level (LCL), and a clear (relatively aerosol free) layer suggesting a wind max (or jet).

In addition, the conical scanning of the HARLIE can be used to study the variability in cloud base and cloud geometry – important in cloud radiation modeling studies and wind speed derivation. Analysis of these quantities is in progress, for this case study, and will be presented during the conference

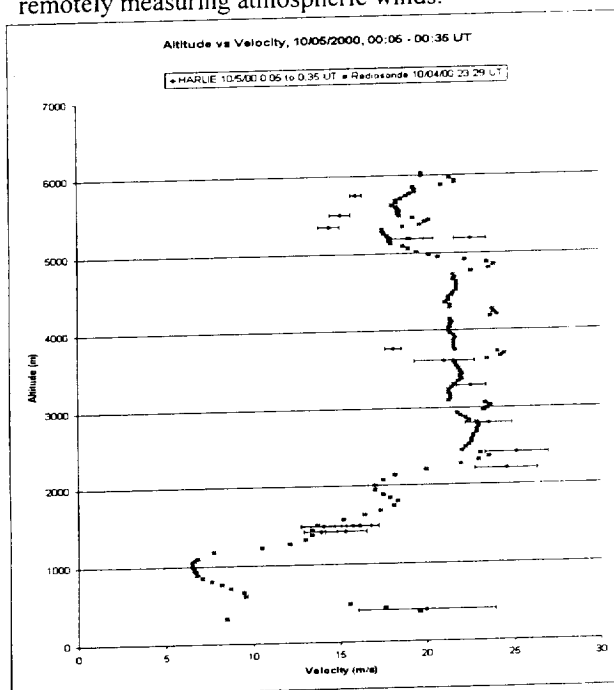


**Figure 3.** False color image of HARLIE measured aerosol backscatter profiles observed on 23 September 2000 showing the details of location of clouds (cloud bases correspond to bases of the white attenuation spikes between 0530 and 1700 UTC) and boundary layer structure during the passage of an undular bore wave ahead of a cold front.

### 3.2 Derived Wind Speed Profiles: 5 October 2000

An exciting data product that may be derived from the HARLIE data are wind vector profiles. This is a new algorithm and uses a technique developed at Utah State University for detecting and measuring the bulk motion of coherent structures in the backscatter field as they progress across the conical scan surface. The method consists of plotting the backscatter data at a fixed altitude as a function of azimuth angle on the Y-axis and time, or scan number on the X-axis. Linear features that move straight across the scan circle (at that altitude) will appear as cosine structures in this "wave" image diagram. The amplitude (or more correctly the slope on the linear portion of the cosine curves) will be proportional to the wind speed, and the phase of the cosines will indicate the direction. An extended discussion of the method by which wind speed profiles are derived from HARLIE backscatter can be found in derivation Wilkerson et al. (2000)

A comparison of such an example is given shown Figure 4. HARLIE-derived winds are compared with the nearest radiosonde wind data from the WVIOP2000 IOP, on 5 October 2000. The HARLIE-derived winds compare well with those measured by radiosonde. This validates the accuracy of this new technique for remotely measuring atmospheric winds.



**Figure 4.** Plot of HARLIE wind speed (left) and direction (right) measurements (black dots), compared with radiosonde derived winds. The error bars represent the RMS of several measurements taken close in time from a single wave image.

### 4. SUMMARY

HARLIE has demonstrated that using a rotating HOE to perform the function of collimating, scanning, and collecting laser light in 1064 nm direct detection lidar systems is a practical and economical alternative to conventional reflective and refractive optical systems. Significant reductions in system size and weight are achieved without sacrificing performance.

We have also shown (and will show at the presentation) that HARLIE measurements can be used can accurately detect, boundary layer structure, wind profiles, and cloud and boundary layer surface inhomogeneity.

### 5. ACKNOWLEDGEMENTS

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### 6. REFERENCES

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